Inhomogeneous condensation in nuclear matter*

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Introduction

Spontaneous breaking of chiral symmetry is a nonperturbative phenomenon in the QCD vacuum as well as at low temperature and densities. Hadronic theories of the low energy regime have to take this into account [1]. Chiral symmetry breaking appears in the hadron spectrum as a mass splitting of so-called chiral partners.

A re-occurring topic in the literature is the possibility that the order parameter for the chiral transition is a function of spatial coordinate [2]. A fruitful Ansatz to describe inhomogeneous condensation is the chiral-density wave (CDW).

We re-investigate the question of inhomogeneous condensation at nonzero density in the extended Linear Sigma Model (eLSM) where the baryons are introduced as parity doublets [3, 4]. The eLSM successfully describes hadron vacuum phenomenology both in the meson and baryon sector, it is therefore a natural choice for non-zero density studies including the CDW [5].

Non-zero density study

In the two-flavor case, $N_f = 2$, the scalar and pseudoscalar mesons are described by the matrix

$$\Phi = (\sigma + \imath\eta_N)t_0 + (\vec{a}_0 + \imath\vec{\pi}) \cdot \vec{t}\,,$$

and the vector and axial-vector mesons by

$$V^\mu = \omega^\mu t_0 + \vec{\rho}^\mu \cdot \vec{t}\,, \quad A^\mu = f_1^\mu t_0 + \vec{a}_1^\mu \cdot \vec{t}\,,$$

where $\vec{t} = \vec{\tau}/2$, with the vector of Pauli matrices $\vec{\tau}$, and $t_0 = \mathbf{1}_2/2$. The model is invariant under the chiral group $SU(2)_R \times SU(2)_L$. The chiral condensate $\phi = \langle\sigma\rangle = Zf_\pi$ emerges upon spontaneous chiral symmetry breaking in the mesonic sector, where $f_\pi \simeq 92.4$ MeV is the pion decay constant and $Z \simeq 1.67$ is the wave-function renormalization constant of the pseudoscalar fields.

We now make the following Ansatz for the condensates, which is of the form of a chiral-density wave:

$$\langle\sigma\rangle = \phi\cos(2fx)\,,\, \langle\pi\rangle = \phi\sin(2fx)\,, \qquad (1)$$

In the limit $f \to 0$ we obtain the usual homogeneous condensation.

The baryons are introduced as two parity doublets Ψ_1 and Ψ_2, which transform according to the mirror assignment:

$$\Psi_{1,R} \to U_R\,\Psi_{1,R}\,, \qquad \Psi_{1,L} \to U_L\,\Psi_{1,L}\,, \qquad (2)$$

$$\Psi_{2,R} \to U_L\,\Psi_{2,R}\,, \qquad \Psi_{2,L} \to U_R\,\Psi_{2,L}\,. \qquad (3)$$

The mirror assignment allows for an additional chirally invariant mass term [6]:

$$m_0\left(\bar{\Psi}_{1,L}\Psi_{2,R} - \bar{\Psi}_{1,R}\Psi_{2,L} - \bar{\Psi}_{2,L}\Psi_{1,R} + \bar{\Psi}_{2,R}\Psi_{1,L}\right)\,. \qquad (4)$$

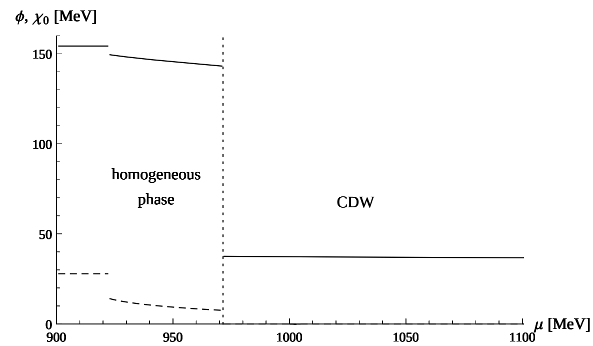

Figure 1: The condensates ϕ and $\bar{\chi}$ are shown as functions of μ.

In Fig. 1 the condensates ϕ and $\bar{\chi}$ are shown as functions of μ. For $\mu = 923$ MeV a first-order phase transition to the nuclear matter ground state takes place and at $\mu = 973$ MeV a transition to the CDW phase occurs. In terms of density, the onset of inhomogeneous condensation is at $2.4\rho_0$. Then, a mixed phase is realized between $2.4\rho_0$ to $10.4\rho_0$. However somewhere in the mixed phase the deconfinement phase transition should occur.

Outlook

Further studies of the model at zero and non-zero densities should be performed to test for general forms of inhomogeneous condensation. The eLSM should be extended to $N_f = 3$ in the baryon sector.

References

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